Influence of Heart Rate on Image Quality to Identify the Best Cardiac Phase in 16-Slice Coronary CT Angiography

Sureeporn Mayurasakorn MD*,
Thanongchai Siriapisith MD*, Jitladda Wasinrat MD*

** Department of Radiology, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok*

Objective: *To identify the best cardiac phase in different patient's heart rate on 16-slice coronary CT angiography.*
Material and Method: *The patients who had undergone coronary CT angiography with 16 multi-detector rows CT at Siriraj Hospital between September 2003 and August 2004. For each patient, the image reconstruction based on relative timing was performed placed at center of 35% to 85% of the R-R interval with step increments 10%. The authors created six data sets (35%, 45%, 55%, 65%, 75%, and 85% of R-R interval) throughout the cardiac cycle. The coronary arteries were reviewed based on cross-sectional images and reformat images. The authors inspected all data sets and selected the cardiac phase that contained the best image quality for each coronary artery.*
Results: *Five hundred sixty four vessels were evaluated in the 141 patients (83 men, 58 women). The mean patient age was 63.3 $\pm$ 16.7 years (range 4-89 years). Mean patient heart rate was 65.7 $\pm$ 16.5 beats per minute (bpm), range 46-104 bpm. The most coronary arteries were well demonstrated at center of 75% of R-R interval (66.8%). Ninety-eight patients (69.5%) required one phase that provided best overall image quality and motion free delineation for four coronary arteries. Forty-three patients (30.5%) required combination of data from each phase to achieve motion free images.*
Conclusion: *The best cardiac phase of evaluate coronary artery in 16 slices coronary CT angiography in the patient's heart rate below 70 bpm is 75% of cardiac cycle (mid to late diastole). In patients with a heart rate 71-80 bpm, the authors required a combination of images from 45% and 75% of cardiac cycle to completely evaluate all coronary arteries. In patients with a heart rate above 80 bpm, 45% of cardiac cycle (end-systole) is the best phase.*

Keywords: *Coronary arteries, Angiography, Image quality, Cardiac imaging, CT, MDCT*

J Med Assoc Thai 2008; 91 (7): 1076-81
Full text. e-Journal: *http://www.medassocthai.org/journal*

Coronary artery disease (CAD) remains the leading cause of death in the world[1]. Conventional coronary angiography is still the gold standard used in the detection and diagnosis of coronary artery disease. The greatest advantage of conventional coronary angiography is high spatial resolution and the preoperative planning for interventions such as ballooning dilatation or coronary stent placement. However, only one-third of all conventional coronary angiographic examinations in the United States are performed in conjunction with an intervention procedure, while the rest are performed only for diagnosis purposes, that is only for verification of the presence and degree of CAD.

Conventional coronary angiography is invasive in nature and as a result, in recent years, a number of noninvasive modalities have found wide applications in the field of cardiac imaging. Most works have used magnetic resonance (MR) imaging and retrospectively gated multi-detector computed tomography (MDCT). However, imaging of the heart has always been technically challenging because of the continuous motion of the heart. Computed tomography (CT) imaging of the heart moves into the diagnostic

Correspondence to: Siriapisith T, Department of Radiology, Faculty of Medicine, Siriraj Hospital, Mahidol University, Bangkok 10700, Thailand. E-mail: sitsa@mahidol.ac.th

realm with the introduction of multi-detector CT and with the development of electrocardiography (EKG)-synchronized scanning and reconstruction technique[1-5]. These modalities permit fast volume coverage and high spatial and temporal resolution. A recent study revealed that the best phase for evaluated coronary artery in patients with a heart rate below 65 beat per min is 75% of R-R interval and in patient with heart rate above 65 beat per min is 45% of R-R interval. The previous study also showed that the best phase is different in each coronary artery. Sixteen slices of CT coronary angiograms were reconstructed such that images of coronary arteries could be examined at various phases of R-R interval from 35%, at steps of 10% to 85% and where the R-R interval will vary depending on the heart rate of each subject. The aim was to determine the phase and the accompanying heart rate at which the quality of the image is cleanest and hence a high confidence in reading.

Material and Method

Patients

CT coronary arteries of one hundred and fifty patients who underwent CT coronary artery for any clinical reasons at Siriraj Hospital from September 2003 to August 2004 were retrospectively reviewed. Nine CT coronary arteries with arrhythmia, defined as difference between minimum and maximum heart rate more than 15 beats per minute, were excluded. This was a retrospective study.

Scan protocol

All CT examinations were performed with 16 slices multi-detector row CT scanner (Lightspeed CT; GE medical systems). The following scanning protocol was used: 16 x 0.625 mm collimation (simultaneous acquisition of sixteen 0.625 mm-thick sections per rotation); automatically adjusted heart rate according to heart rate; 500 msec rotation time; 120 kV and 440 mA; To calculate the scanning delay, a test bolus 20 ml of contrast material at flow rate 4 ml per second. The arrival time at ascending aorta was calculated by measuring peak CT attenuation at ascending aorta plus 2 seconds. The contrast injection was 120 ml bolus of nonionic contrast material (350-370 mg of iodine per milliliter) by a single syringe power injector. The ECG monitoring was simultaneously triggered with CT scan.

For images reconstruction using retrospective EKG gating and the 240° multi-slice cardiac interpolation algorithm, the authors reconstructed cross-section images with a slice thickness of 0.625 mm and 0.625 mm interval. The field of view was 15-20 cm with an image matrix of 512 x 512 pixels. For each patient, the image reconstruction based on relative timing was performed with the first reconstruction interval being placed at the center of 35%of the R-R interval and the last reconstruction interval being placed at the center of 85% of the R-R interval. Image reconstruction intervals were placed in step increment of 10%. Therefore, the authors created six data sets (35%, 45%, 55%, 65%, 75%, and 85% of R-R interval) throughout the cardiac cycle (Fig. 1). The image data from each of these reconstructions were transferred to a computer workstation (advantage workstation; GE medical system).

Images analysis

The best image was determined subjectively and resulted from an agreement of the two observers (2 and 4 years experience with coronary CT angiography) who were unaware of the clinical condition. The length of vessel that was acceptable was not stated at each of the four sites (LM, LAD, LCX, and RCA). The final decision was reached by consensus. The coronary arteries were reviewed based on cross-sectional images and reformat images. The authors inspected all data sets and selected the data set that contained the best image quality for each coronary artery.

The best image quality was attributed to the vessels appearing as bright circular or oval areas surrounded by low-attenuation fat tissue, present discrete blurring of the vessel margin and had least motion artifact (discrete tail or streak-emitting shadows).

Results are documented separately for the major epicardial arteries according to American Heart Association guidelines[6]: left main artery (LM), left anterior descending artery (LAD), left circumflex artery (LCX), and right coronary artery (RCA).

Results

Five hundred sixty four vessels (LM, LAD, LCX and RCA) were evaluated in the 141 patients (83 men, 58 women). The mean patient age was 63.3 $\pm$ 16.7 years (range 4-89 years). Mean patient heart rate was 65.7 $\pm$ 16.5 beats per minute (bpm), range 46-104 bpm. The patients were divided into four groups. Fifty-one (36.2%) patients had a heart rate below 60 bpm (group 1). Thirty-nine patients (27.7%) had a heart rate between 61 to 70 bpm (group 2). Twenty-three patients (16.3%) had a heart rate between 71 to 80 bpm (group 3) and twenty-eight patients (19.8%) had a heart rate above 80 bpm (group 4) (Table 1).

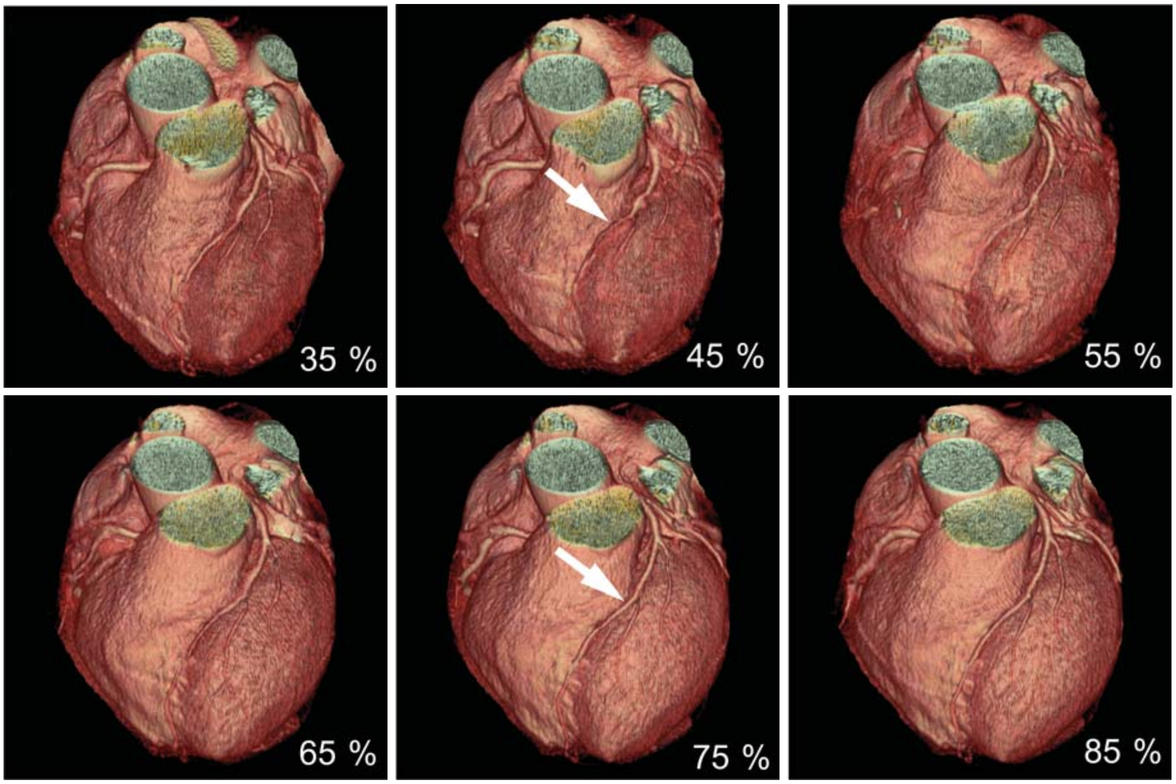

Fig. 1 Image quality in different phases of coronary CT angiography (35%, 45%, 55%, 65%, 75%, 85% of R-R interval). The 3D volume rendering of patient undergone coronary CT angiography below 60 bpm of heart rates demonstrates the best and worse image quality of LAD at 75% and 45% of R-R interval (arrow), respectively

The most of the coronary arteries (66.8%) (377/564 arteries) were well demonstrated at 75% of cardiac cycle. The second best image quality was at 45% of cardiac cycle for 22.5% (127/564 arteries). The remaining cardiac cycles were well demonstrated in only 10.7% of all coronary arteries (2.7% on 35% of cardiac cycle, 3.9% on 55% of cardiac cycle, 1.4% on 65% of cardiac cycle and 2.7% on 85% of cardiac cycle).

Table 1. The characteristics of patients imaged with 16 slices coronary CT angiography

No. of patients	141
Age (years)	63.3 $\pm$ 16.7
Male-to-female ratio	83:58
Average heart rate (beats/min)	65.7 $\pm$ 16.5
No. of group 1 patient ($\leq$ 60 bpm)	51 (36.2%)
No. of group 2 patient (61-70 bpm)	39 (27.7%)
No. of group 3 patient (71-80 bpm)	23 (16.3%)
No. of group 4 patient ($\geq$ 81 bpm)	28 (19.8%)

For all coronary analysis, the best image quality in group 1 and 2 were at 75% of cardiac cycle. Group 3 was also at 75% of cardiac cycle, which was slightly better than at 45% of cardiac cycle. Finally, in group 4, the best image quality was at 45% of cardiac cycle.

For the left main coronary artery, the best image quality in group 1, 2 and 3 were at 75% of cardiac cycle. For group 4, it was at 45% of cardiac cycle.

For the left anterior descending artery, the best image quality in group 1, 2 and 3 was at 75% of cardiac cycle. For group 4, it was at 45% of cardiac cycle.

For the left circumflex artery, the best image quality in group 1, 2 and 3 were at 75% of cardiac cycle. For group 4, it was at 45% of cardiac cycle.

For the right coronary, the best image quality in group 1 and 2, were at 75% of cardiac cycle. For group 3 and 4, there were at 45% of cardiac cycle.

Ninety-eight patients (69.5%) required one phase that provided best overall image quality and motion free delineation for four coronary arteries. Forty-three patients (30.5%) required a combination of data from each phase to achieve motion free images.

Discussion

Five hundred sixty four vessels (LM, LAD, LCX, and RCA) were evaluated in the 141 patients. This was done 16-slices coronary CT angiography. The recent technology with high temporal resolution frequently does not completely eliminate motion artifact so that required less cardiac movement for coronary artery evaluation. The mid to late diastole cardiac phase frequently yielded the best image quality of left main (LM), left anterior descending (LAD), left circumflex (LCX), and right coronary artery (RCA).

The present study showed that the heart rate strongly influenced the best cardiac phase (Table 2, 3). The best image window in patients with a heart rate below 60 bpm and 61-70 bpm were usually during 75% of cardiac cycle (mid to late diastole) about 93.1% (190/204 arteries) and 79.5% (124/156 arteries), respectively. In patients with a heart rate of 71-80 bpm there was a best image quality in two cardiac phases at 45% and 75% of the cardiac cycle about 39.1% (36/92 arteries) and 44.6% (41/92 arteries), respectively. The result showed that for a slow heart rate ≤ 70 bpm the phase at 75% of the R-R interval gives the most pleasing image and for faster heart rate, 45%, of R-R internal is better. It is strange that 45% and 75% seemed very well demarcated with very little high quality at 55%, 65%, and 85%. Because of the shorter duration of diastolic relaxation in faster heart rate, the best cardiac phase for visualization of the coronary arteries in patients with a heart rate more than 80 bpm was more frequently during 45% of cardiac cycle (end-systole) about 59.8% (67/112 arteries).

The residual cardiac motion artifacts remain a major cause of image degradation in multi-detector row CT coronary artery. Physiological high velocity phase of cardiac motion are early-mid systole, early-mid diastole (rapid filling of ventricle), and end diastole (atrial contraction). The two regions of reduced velocity are end-systole (isovolumic relaxation of the ventricle, at approximately 50%of cardiac cycle) and mid-diastole (approximately 80% of cardiac cycle). In previous study, Achenbach et al [7] studied the coronary artery motion on transverse electron-beam CT images. They found that the lowest mean in-plane velocity of the coronary arterial motion in all three coronaries was found at 48% of cardiac cycle. While at 80% of the cardiac cycle (the phase that is usually used in current practice), the

Table 2. Amount of coronary arteries which have best image quality in 141 patients group by each coronary artery

Coronary artery	Cardiac phase with best image quality (No. of coronary arteries)						Total
	35%	45%	55%	65%	75%	85%	
Right coronary artery	4	39	11	3	78	6	141
Left main	4	30	4	2	98	3	141
Left anterior descending	5	26	5	2	100	3	141
Left circumflex	2	32	2	1	101	3	141
Total	15 (2.7%)	127 (22.5%)	22 (3.9%)	8 (1.4%)	377 (66.8%)	15 (2.7%)	564

Table 3. Amount of coronary arteries which have best image quality in 141 patient group by heart rate

Heart rate (beat/min)	No. of patients	No. of arteries	Cardiac phase with best image quality (No. of coronary segment)						Total
			35%	45%	55%	65%	75%	85%	
≤ 60	51	204	3	1	0	4	190	6	204
61-70	39	156	2	23	3	2	124	2	156
71-80	23	92	4	36	7	0	41	4	92
≥ 81	28	112	6	67	12	2	22	3	112
Total	141	564	15	127	22	8	377	15	564

velocity of the three coronaries was not significantly greater than at 48% of the cardiac cycle. A similar result has been reported in the study of Hofman et al[8] and Hoffmann et al[9].

It has been documented and worldwide accepted that as the heart rate increases, the image quality will decrease. Giesler et al [10] found that as the heart rate increase, the number of arteries that could be evaluated decreased, and overall sensitivity for stenosis detection decreased. Hoffmann et al studied the effect of heart rate to image quality[9] and found that the best image quality was achieved at 80 bpm or below. They also found that good image quality is achievable at slow heart rate using a mid-end diastolic phase frame and shifting to end-systolic frames as heart rate increases. The same result is shown in the present study, probably because a faster heart rate leads to a shorter R wave-to-R wave interval resulting in the shorter end diastolic portion of the cardiac cycle. Based on the anatomy, the mid-segment of right coronary artery and left circumflex artery are located in the atrio-ventricular groove and therefore, are subjected to substantial lateral displacement that is caused by atrial contraction. Therefore, these two arteries exhibit high velocity and motion artifact. In contrast, a significant portion of left anterior descending artery runs along the anterior surface of the left ventricular wall and is not subjected to sudden motion, and consequently exhibits lower average velocities and motion artifact. Achenbach et al[7] found that the mean velocity of RCA motion was significantly faster than that of LAD or LCX. Giesler et al[10] found that each of the coronary has a different motion pattern during the cardiac cycle. As the heart rate increases, images of the RCA were the most frequently affected image quality earlier than the LAD or LCX. In comparison to our the present study, the authors did not measure the velocity of the coronary artery but shifting of the best phase from mid-end diastolic phase frame to end-systolic frame as heart rate increases of RCA was shown as the same fashion as the LAD and LCX. Most of the best image quality of RCA in patients whose heart rate 71-80 bpm is 45% of R-R interval, while the other is 75%. The explanation by the theory of Achenbacn et al[7] showed that the mean velocity of RCA motion was significantly faster than LAD or LCX. The variation of the best position of the image reconstruction window and the differences between the coronary arteries suggest that careful selection of the image reconstruction window are crucial factors to obtaining best image quality and diagnosis accuracy on MDCT.

The present study was used to make the decision of best reconstruction window selection during scanning according to heart rate in retrospective reconstruction. In prospective reconstruction, it can be used for coronary CT angiography that reconstruct only one cardiac phase during scanning by modulating mA during heart cycle to achieve dose reductions in cardiac studies. The present study showed a guideline for best cardiac phase selection for prospective reconstruction of coronary artery.

The main limitation of the study is that it is a retrospective study. The present study divided the cardiac phase into only six phases. More accurate evaluation of cardiac would required more cardiac phases and less percent increment for evaluation. In addition, the present study did not evaluate the degree of coronary stenosis.

The authors conclude that the desired physiological phases for evaluate coronary arteries in patients with a heart rate below 70 bpm is 75% of the cardiac cycle (mid to late diastole). In patients with a heart rate of 71-80 bpm, the authors required a combination of image from 45% and 75% of cardiac cycle to completely evaluate all coronary arteries. For patients with a heart rate above 80 bpm, 45% of cardiac cycle (end-systole) is the best.

References

1. Flohr TG, Schaller S, Stierstorfer K, Bruder H, Ohnesorge BM, Schoepf UJ. Multi-detector row CT systems and image-reconstruction techniques. Radiology 2005; 235: 756-73.
2. Kopp AF, Schroeder S, Kuettner A, Heuschmid M, Georg C, Ohnesorge B, et al. Coronary arteries: retrospectively ECG-gated multi-detector row CT angiography with selective optimization of the image reconstruction window. Radiology 2001; 221: 683-8.
3. Nieman K, Cademartiri F, Lemos PA, Raaijmakers R, Pattynama PM, de Feyter PJ. Reliable noninvasive coronary angiography with fast submillimeter multislice spiral computed tomography. Circulation 2002; 106: 2051-4.
4. Schoenhagen P, Halliburton SS, Stillman AE, Kuzmiak SA, Nissen SE, Tuzcu EM, et al. Noninvasive imaging of coronary arteries: current and future role of multi-detector row CT. Radiology 2004; 232: 7-17.
5. Schoepf UJ, Becker CR, Ohnesorge BM, Yucel EK. CT of coronary artery disease. Radiology 2004; 232: 18-37.

6. Austen WG, Edwards JE, Frye RL, Gensini GG, Gott VL, Griffith LS, et al. A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. Circulation 1975; 51: 5-40.
7. Achenbach S, Ropers D, Holle J, Muschiol G, Daniel WG, Moshage W. In-plane coronary arterial motion velocity: measurement with electron-beam CT. Radiology 2000; 216: 457-63.
8. Hofman MB, Wickline SA, Lorenz CH. Quantification of in-plane motion of the coronary arteries during the cardiac cycle: implications for acquisition window duration for MR flow quantification. J Magn Reson Imaging 1998; 8: 568-76.
9. Hoffmann MH, Shi H, Manzke R, Schmid FT, De Vries L, Grass M, et al. Noninvasive coronary angiography with 16-detector row CT: effect of heart rate. Radiology 2005; 234: 86-97.
10. Giesler T, Baum U, Ropers D, Ulzheimer S, Wenkel E, Mennicke M, et al. Noninvasive visualization of coronary arteries using contrast-enhanced multidetector CT: influence of heart rate on image quality and stenosis detection. AJR Am J Roentgenol 2002; 179: 911-6.

การศึกษาอิทธิพลชีพจรที่มีผลต่อคุณภาพของภาพเพื่อแสดงช่วงจังหวะการเต้นของหัวใจที่ดีที่สุดในการตรวจหลอดเลือดหัวใจด้วยเอซเรย์คอมพิวเตอร์ชนิด 16 หัวตรวจ

สุรีย์พร มยุระสาคร, ทนงชัย สิริอภิสิทธิ์, จิตรลัดดา วะศินรัตน์

วัตถุประสงค์: *เพื่อศึกษา cardiac phase ที่ให้ภาพหลอดเลือดหัวใจที่ดีที่สุด ในการตรวจเอกซเรย์คอมพิวเตอร์หลอดเลือดหัวใจด้วยเครื่องเอกซเรย์คอมพิวเตอร์ชนิด 16 slices*

วัสดุและวิธีการ: *ผู้ป่วยที่ได้รับการตรวจหลอดเลือดหัวใจด้วยเครื่องเอกซเรย์คอมพิวเตอร์ชนิด 16 slices ในโรงพยาบาลศิริราชตั้งแต่กันยายนปี พ.ศ. 2546 จนถึง สิงหาคม พ.ศ. 2547 ผู้ป่วยแต่ละรายได้รับการสร้างภาพหลอดเลือดหัวใจที่ตำแหน่งต่าง ๆ ของ cardiac phase ตั้งแต่ 35% จนถึง 85% ของ R-R interval โดยเว้นช่วงทีละ 10% ทำให้เกิด ข้อมูลจำนวน 6 ชุด (35%, 45%, 55%, 65%, 75% และ 85% ของ R-R interval) ข้อมูลที่ได้นำมาทำการศึกษาเพื่อหา cardiac phase ที่ดีที่สุดสำหรับหลอดเลือดหัวใจแต่ละเส้น*

ผลการศึกษา: *หลอดเลือดหัวใจจำนวน 564 หลอดเลือดจำนวนผู้ป่วย 141 ราย (ชาย 83 ราย,หญิง 58 ราย) ได้ถูกนำมาศึกษา อายุเฉลี่ยผู้ป่วย 63.3 $\pm$ 16.7 ปี (ช่วงระหว่าง 4 ถึง 89 ปี) ชีพจรโดยเฉลี่ย 65.7 $\pm$ 16.5 ครั้งต่อนาที ช่วงระหว่าง 46 ถึง104 ครั้งต่อนาที การศึกษาพบว่าหลอดเลือดหัวใจส่วนใหญ่จะเห็นได้ชัดเจนที่ 75% ของ R-R interval (66.8%) ผู้ป่วยจำนวน 98 ราย (69.5%) ต้องการเพียง cardiac phase เดียวก็ให้ภาพชัดเจนเพียงพอสำหรับหลอดเลือดหัวใจทั้งสี่เส้น ผู้ป่วยจำนวน 43 ราย (30.5%) จำเป็นต้องใช้ข้อมูลมากกว่า 1 cardiac phase เพื่อให้การวินิจฉัย*

สรุป: *Cardiac phase ที่ดีที่สุดสำหรับการศึกษาหลอดเลือดหัวใจด้วยการตรวจด้วยเครื่องเอกซเรย์คอมพิวเตอร์ชนิด 16 slices ในผู้ป่วยที่มีชีพจรช้ากว่า 70 ครั้งต่อนาทีคือ 75% ของ R-R interval, ในผู้ป่วยที่มีชีพจร 71-80 ครั้งต่อนาทีต้องการภาพที่ 45% และ 75% ของ R-R interval ในการแปลผลภาพหลอดเลือดหัวใจทั้งหมด และ 45% ของ R-R interval สำหรับผู้ป่วยที่มีชีพจรเร็วกว่า 80 ครั้งต่อนาที*